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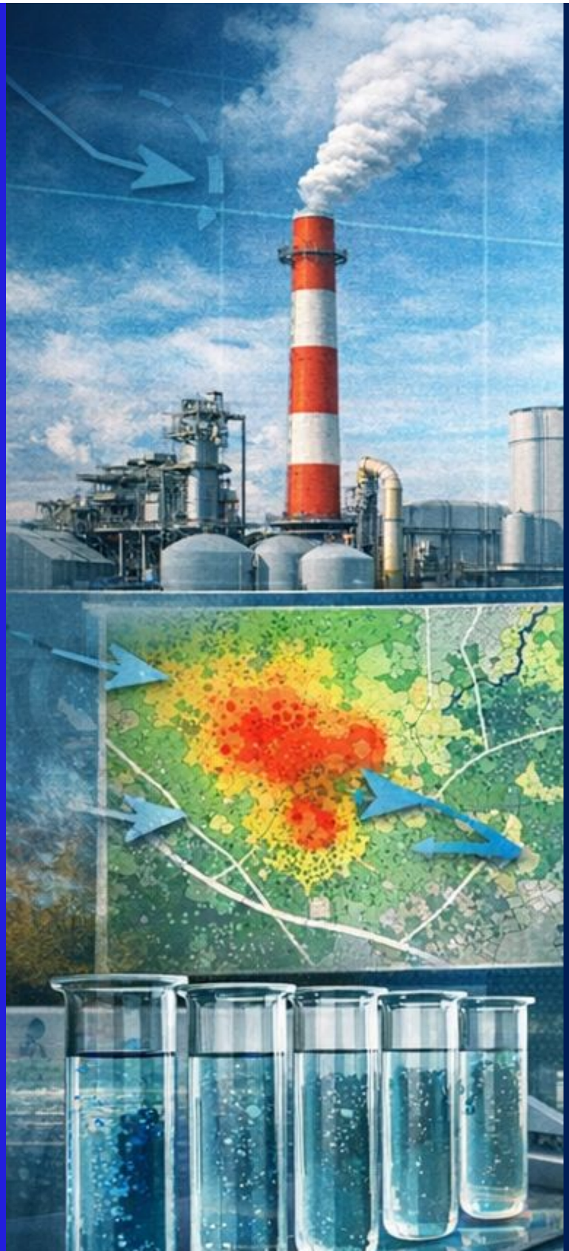
Challenging today.
Reinventing tomorrow.

PFAS Visualization and Fingerprinting for PFAS Site Investigation and Source Identification

The 14th Annual Brownfield Seminar
Georgia Brownfield Association

April 16, 2026



PFAS Problem Statement

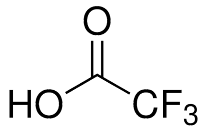
- A growing obstacle due to PFAS persistence, mobility, evolving regulations, and health risks
- Lack of PFAS impact characterization resulting in uncertainties around risk, cleanup obligations and redevelopment feasibility
- Lack of effective remediation strategies delaying site reuse, increasing cost

- Benefits of PFAS investigation and fingerprinting
  - Differentiate on-site vs off-site sources, legacy vs current operations
  - Reducing open-ending PFAS liability, making financing and property transfer more feasible
  - Providing defensible technical evidence for CSM
  - Supporting negotiation on cleanup scope, timing and endpoints

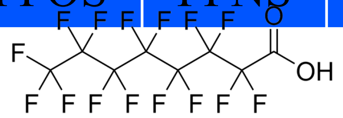
Complexity of PFAS Chemistry

- **Terminal PFAA: Ultrashort, short- and long-chain PFCAs and PFSAs**

Carbon No.	2	3	4	5	6	7	8	9	10	11	12
PFCAs	Ultrashort		Short -Chain				Long-Chain				
	TFA	PFPrA	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFSAs			Short-Chain		Long-Chain						
			PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS

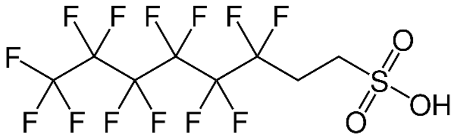


TF
A

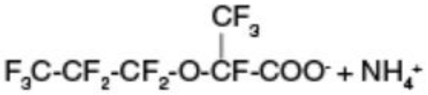


PFO
A

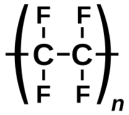
- **PFAS precursors**
- **PFAA replacements** such as GenX chemicals
- **Polymeric PFAS**
- **HFCs: Hydrofluorine carbons**



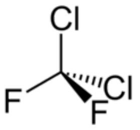
6:2 fluorotelomer sulfonic acid



GenX Ammonium Salt



Polytetrafluoroethylene (PTFE)



Dichlorodifluoromethane

PFAA: perfluoroalkyl acids
PFCA: perfluoroalkyl carboxylic acids
PFSA: perfluoroalkyl sulfonic acids

Draft Contaminant Candidate List (CCL) 6 List on PFAS

- CCL4 (2016)
- Final regulatory determination in Feb 2021
- PFOA
- PFOS

- CCL5 (2022)
- National primary drinking water regulation (NPDWR) in April 2024
  - PFOA, PFOS
  - PFHxS, PFNA, PFBS
  - GenX
  - PFAS mixtures via Hazard Index
- Develop class-based “thinking”

- **Draft** CCL6 (April 2, 2026)
- 75 chemicals and 4 chemical groups, including PFAS
- PFAS as a class exclude the ones covered under NPDWR
  - R-(CF2)-CF(R′)R″
  - R-CF2OCF2-R′
  - CF3C(CF3)RR′
  - None of R groups can be hydrogen
- It matters for **background study, forensic differentiation, future cumulative SDWA risk evaluation**

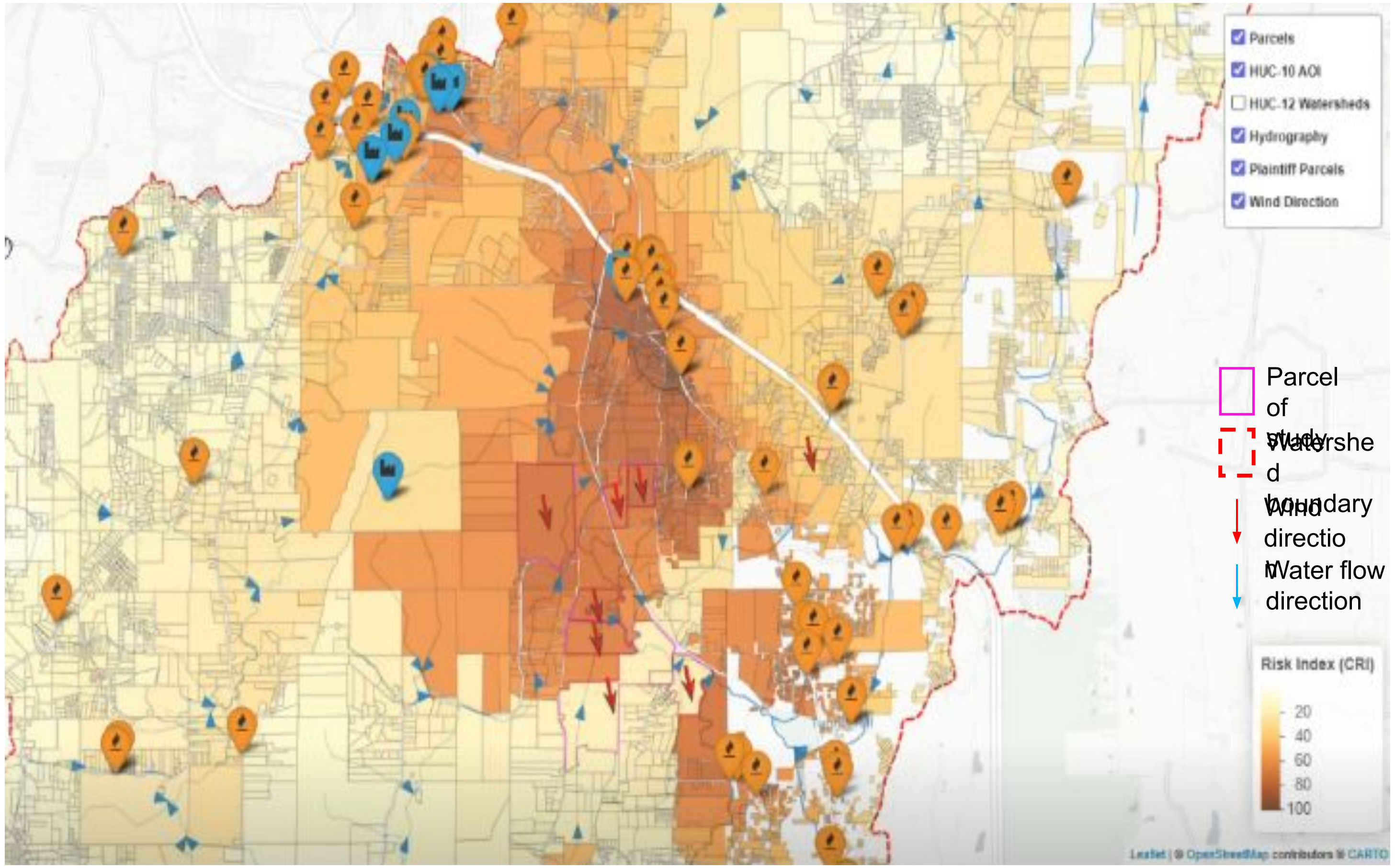
Industrial Sectors - PFAS Sources

Oil and Gas Extraction	Mining	Sewage Treatment Facilities	Textile Mills
Textile Product Mills	Leather and Allied Product Manufacturing	Paper Manufacturing	Printing and Related Support
Petroleum and Coal Products Manufacturing	Chemical Manufacturing	Plastics and Rubber Products Manufacturing	Capet/Flooring/Building Material Manufacturing
Primary Metal Manufacturing	Fabricated Metal Product Manufacturing	Machinery Manufacturing	Computer and Electronic Product Manufacturing
Electrical Equipment	Appliance, and Component Manufacturing	Petroleum and Bulk Terminals	Surgical and Medical Instrument Manufacturing
Airports, Port and Harbor Operations	Carpet and Upholstery Cleaning	Rail and Truck Transportation	Waste Management
Car Wash, Furniture Repair	Dry Cleaner and Laundry Operators	Fire Protection	National Security, Defense Sectors

https://www.govinfo.gov/content/pkg/FR-2024-05-08/pdf/2024-08547.pdf

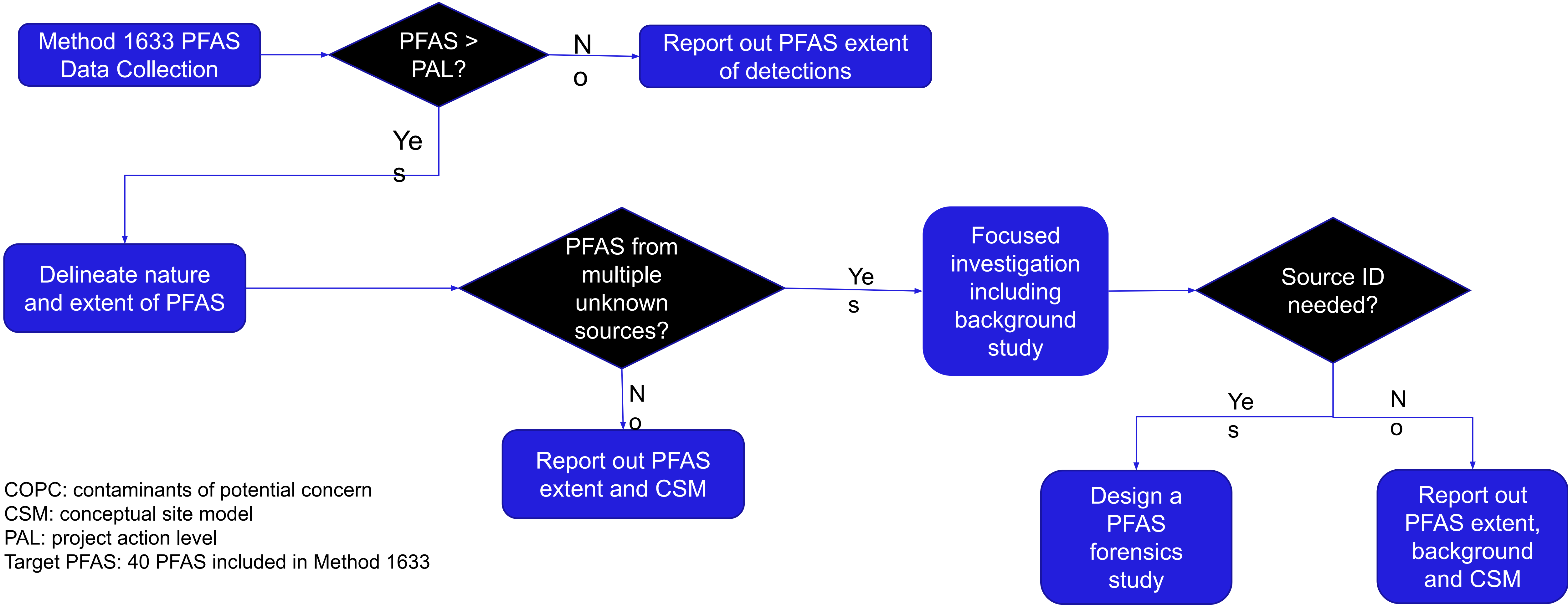
PFAS Impact Risk Mapping for Preliminary PFAS Impact Screening

- Conducted prior to PFAS background data collection
- Help identify the need of background study through sample collection
- Help select background sampling locations
- Help justify RI, forensics and cleanup strategy
- Record searches on land uses, WWTP residual's land applications, PFAS source types and release history, climate conditions, hydrogeological features
- Each parcel within study area has a calculated risk index based on suspect PFAS sources, migration pathways (source release pathways, surface water and wind directions), and distances to PFAS sources



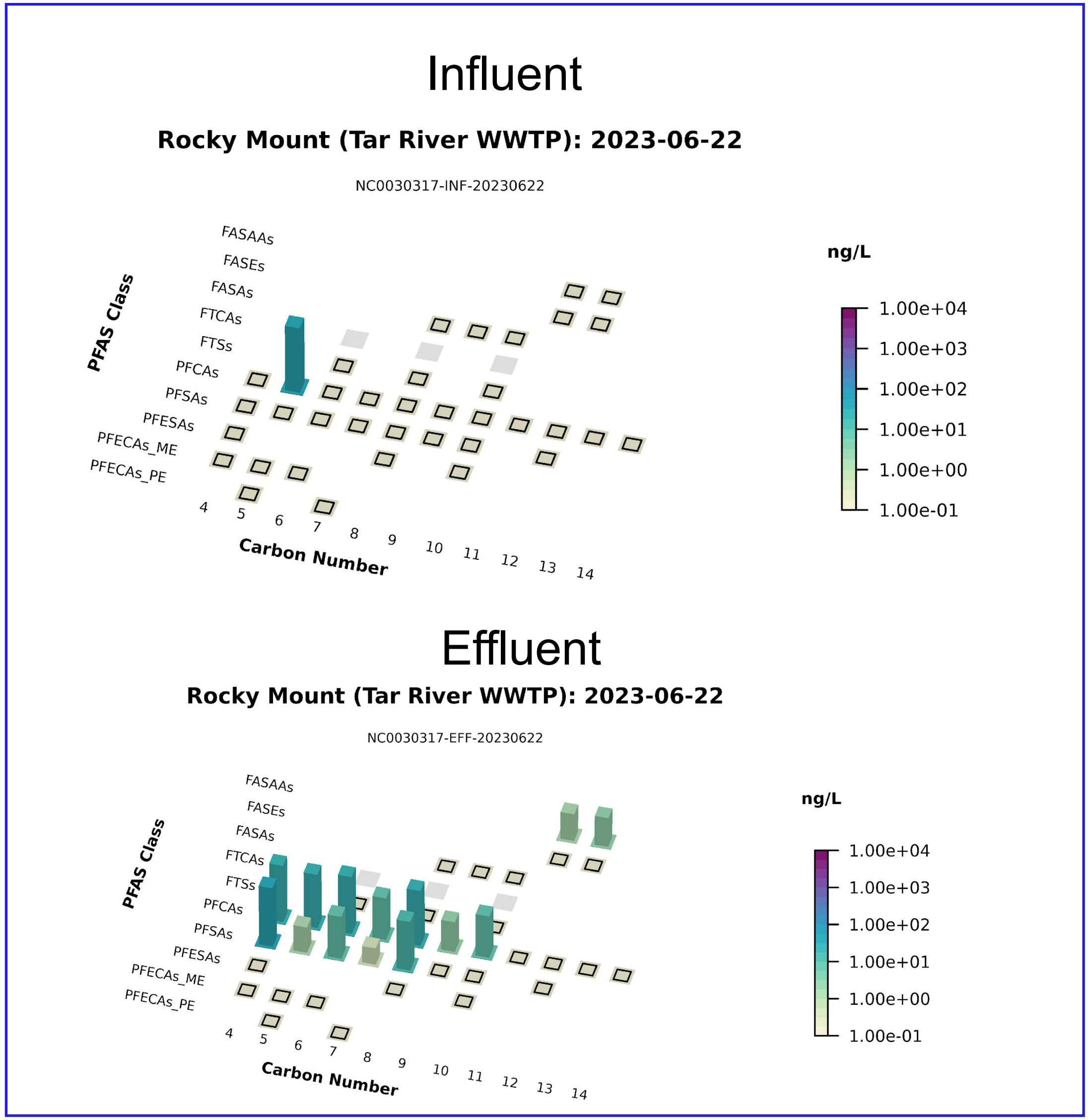
Credit: Jacobs PFAS Impact Risk Mapping Tool

PFAS Investigation – Example Workflow

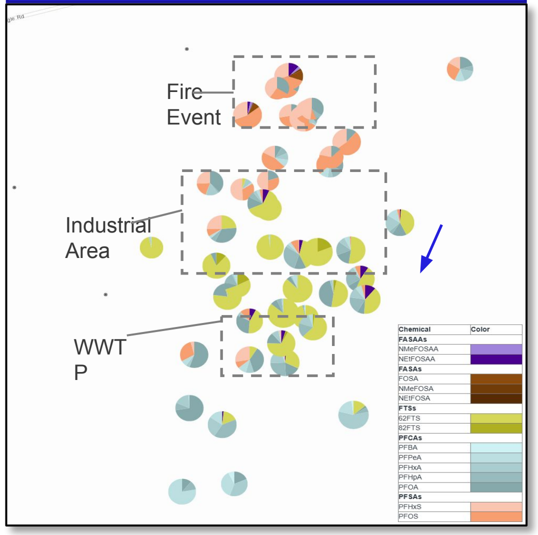


COPC: contaminants of potential concern
CSM: conceptual site model
PAL: project action level
Target PFAS: 40 PFAS included in Method 1633

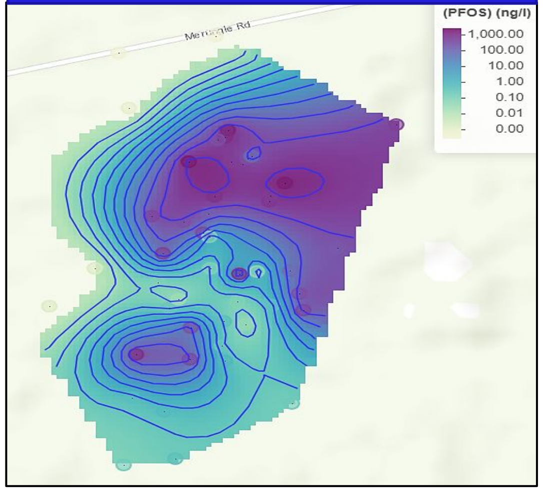
Example Types of Automated Processed $PFAS_{40}$ Data Visualization



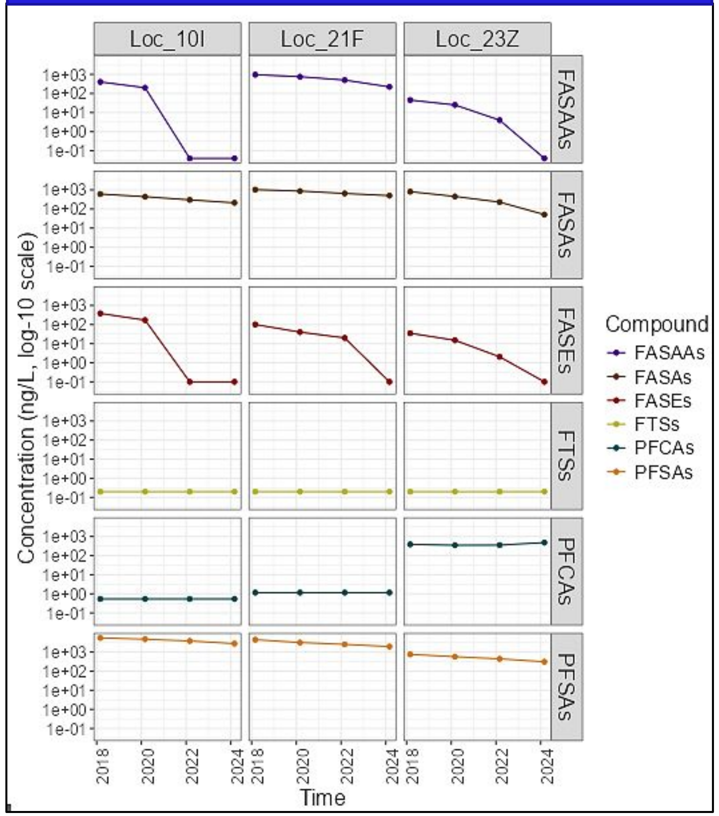
PFAS Variability Across a Site



Geostatistical Analysis

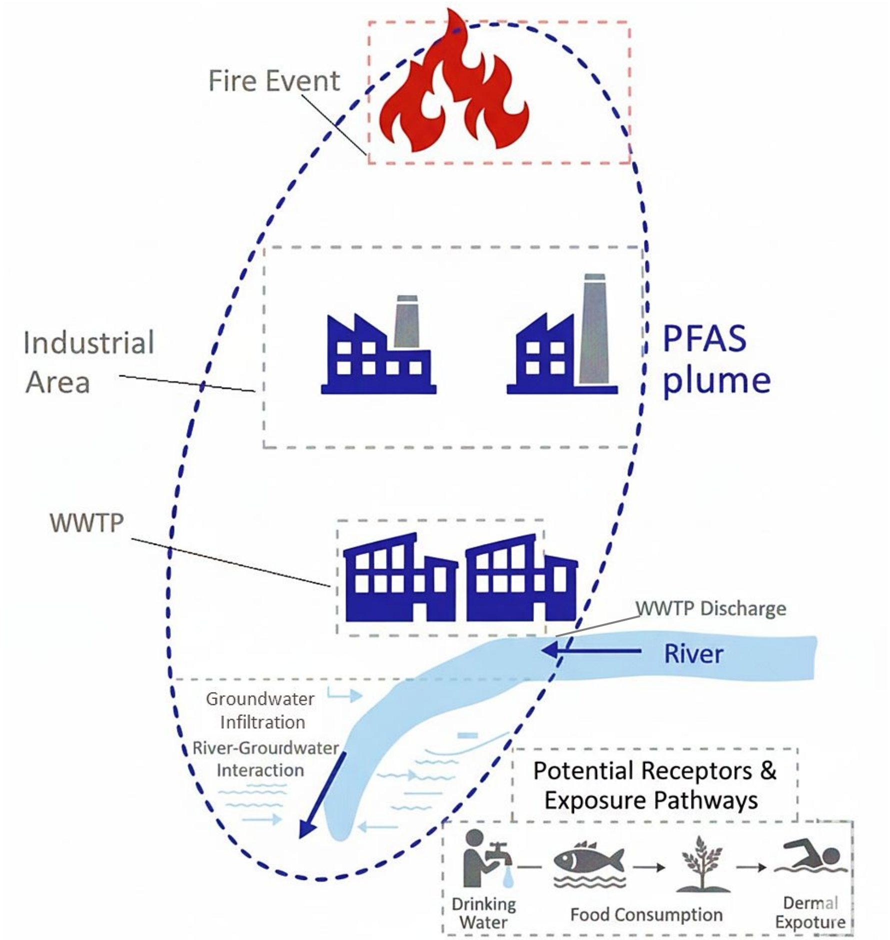


Temporal Trends

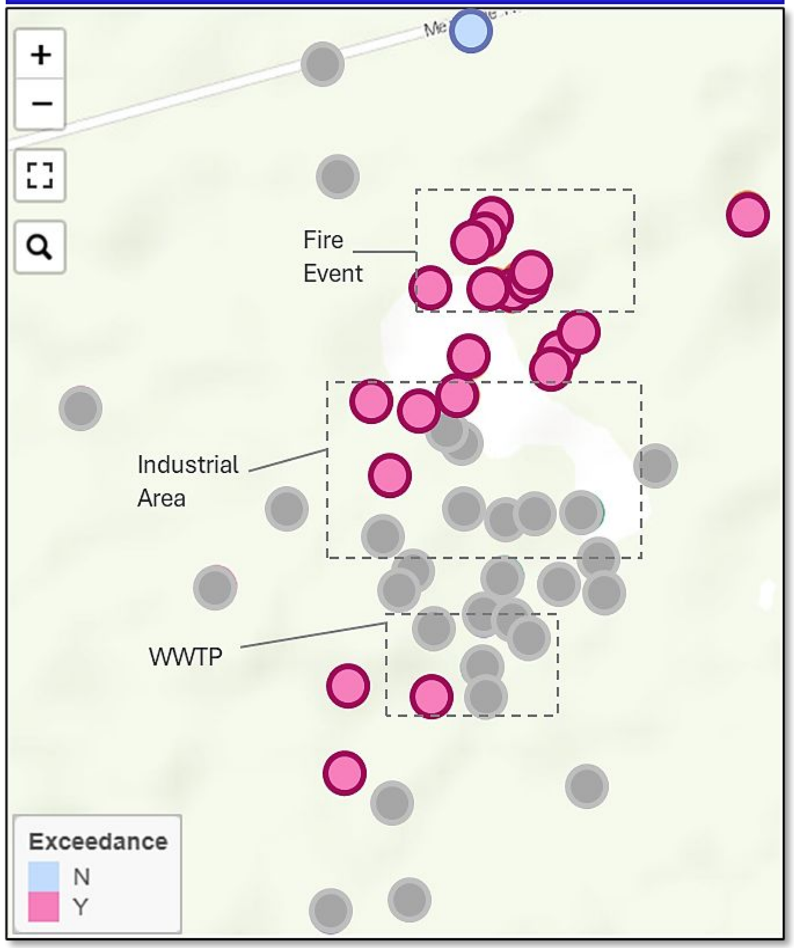


Example Types of Automated Processed $PFAS_{40}$ Data Visualization

Industrial PFAS Investigation Case Study

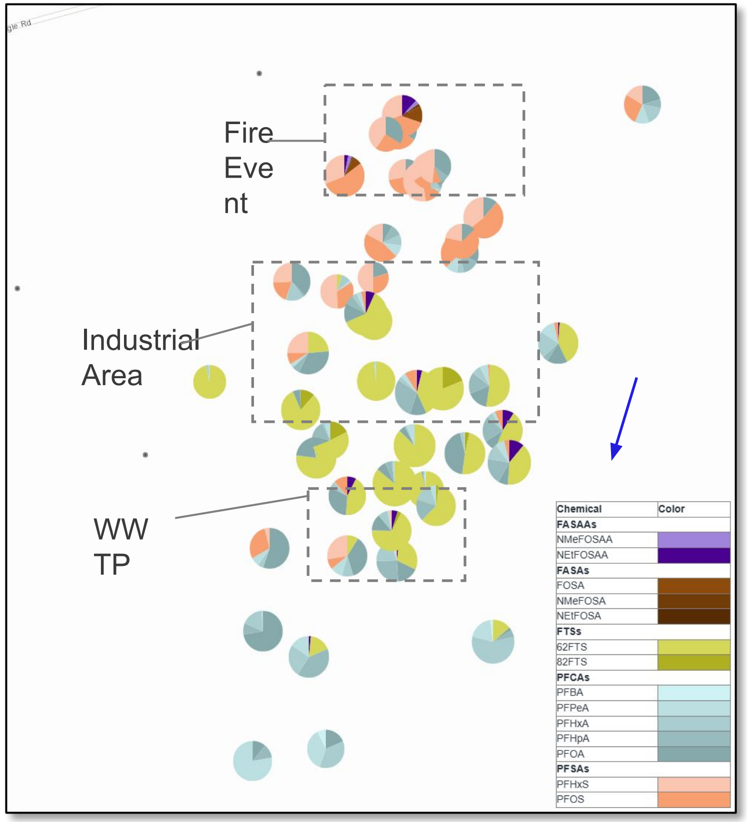


PFAS Exceedances



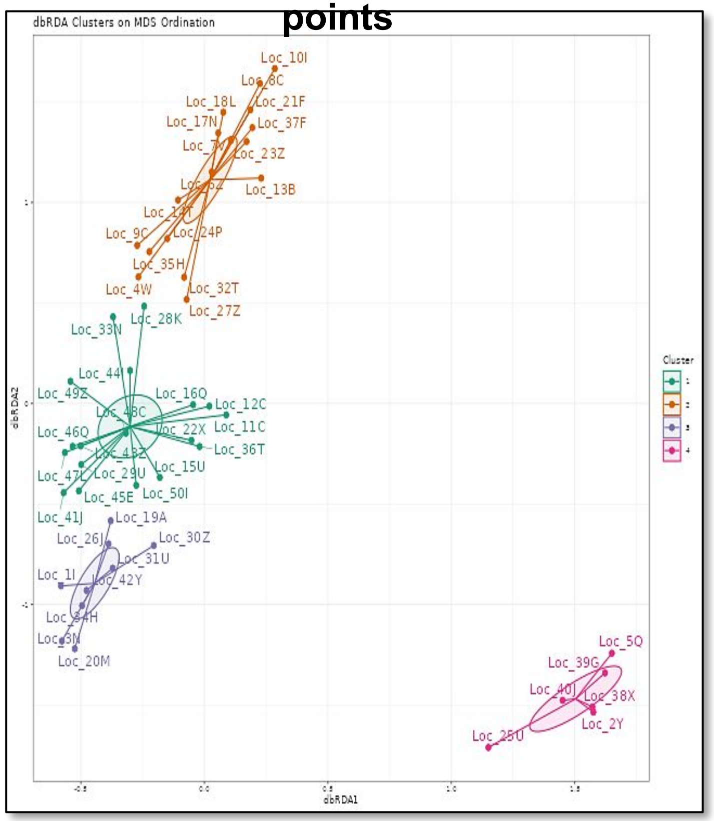
Example Types of Automated Processed $PFAS_{40}$ Data Visualization
Industrial PFAS Investigation Case Study

PFAS Pie Charts
PFAS investigation to verify PFAS extents and chemical compositions

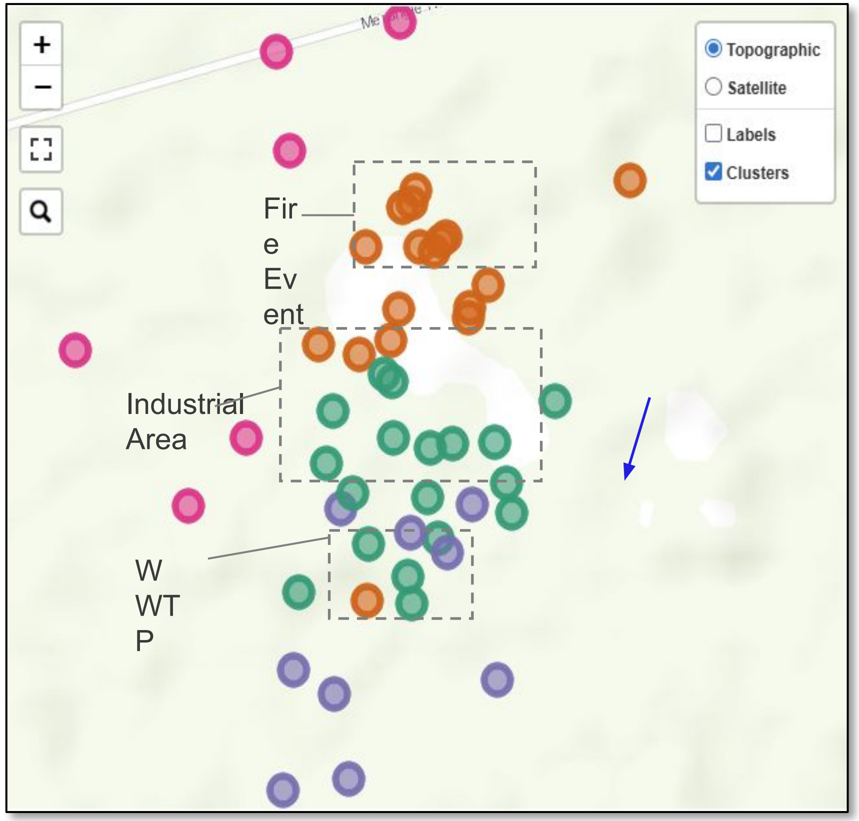


GW flow direction

PFAS Cluster Analysis
Statistically differentiate PFAS compositions between data points



PFAS Cluster Analysis
Identification of PFAS data similarity and differences across the site



Example Types of Automated Processed $PFAS_{40}$ Data Visualization
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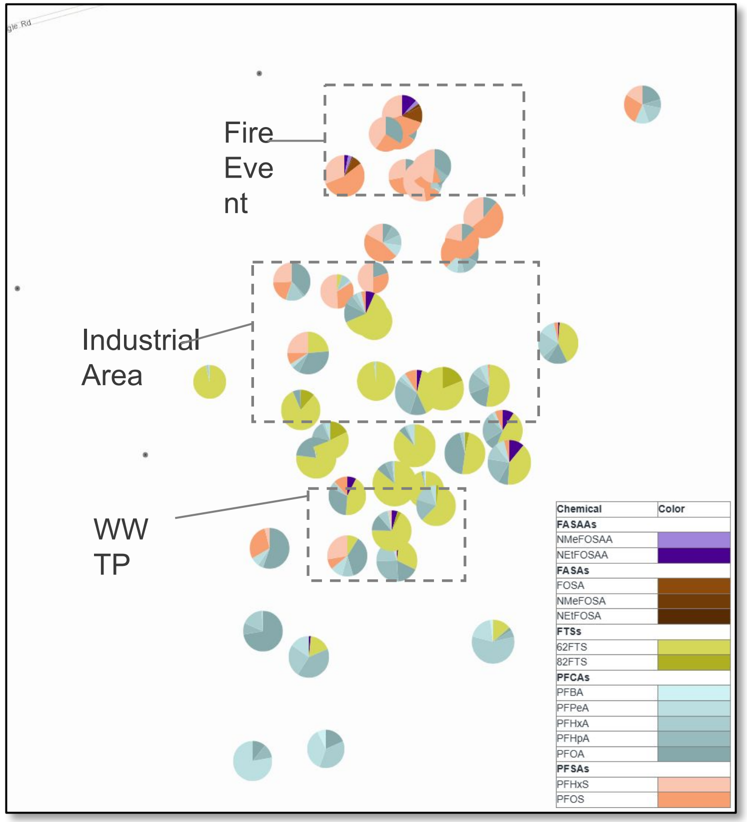

GW flow direction

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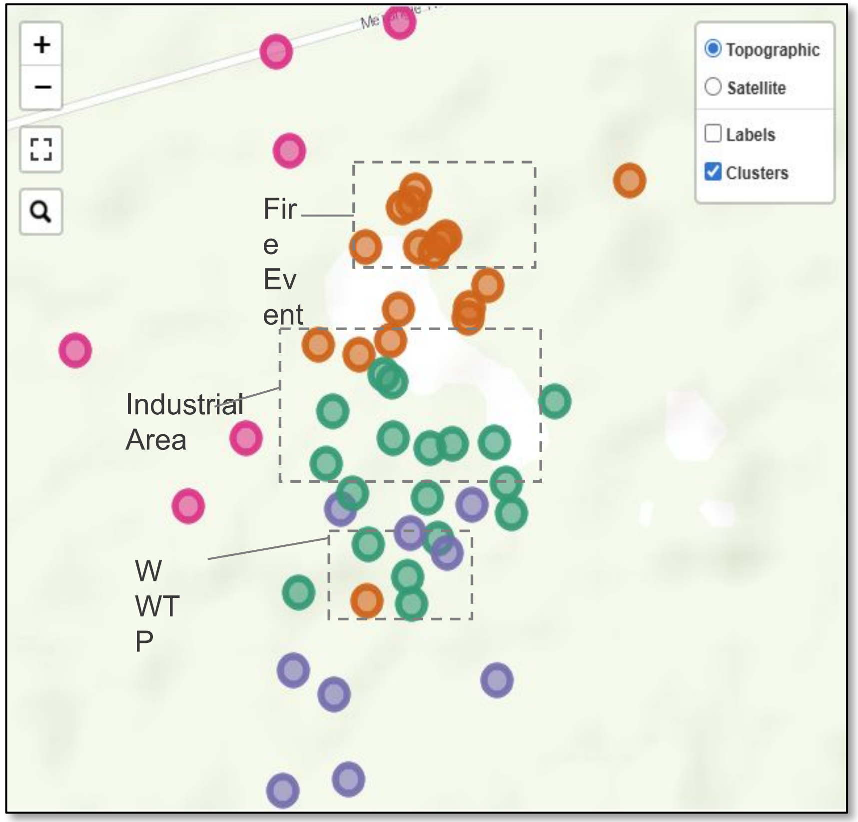
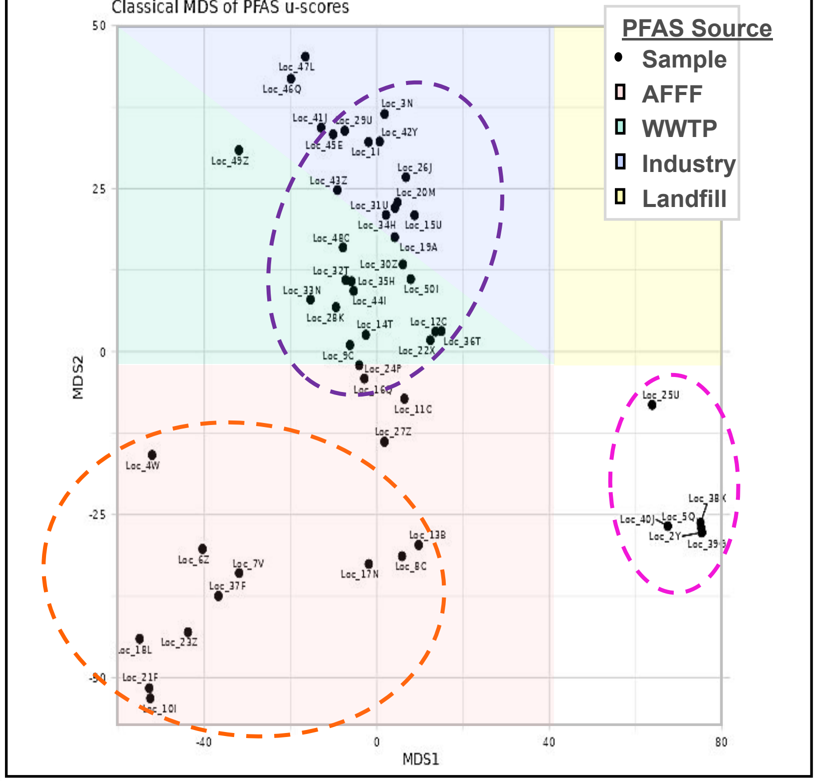
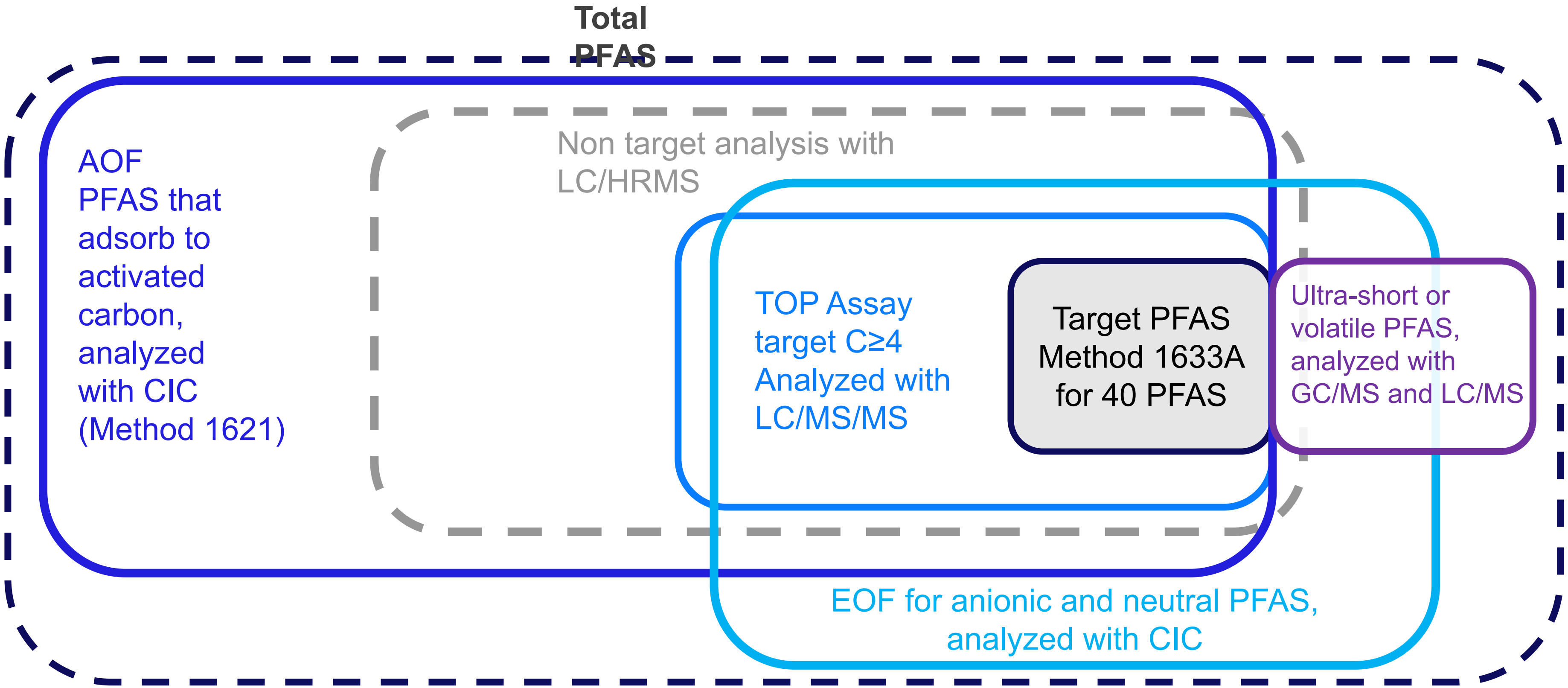


PFAS Source Identification
Matching PFAS data to chemical signatures of different PFAS sources, separating multiple on-site and off-site sources



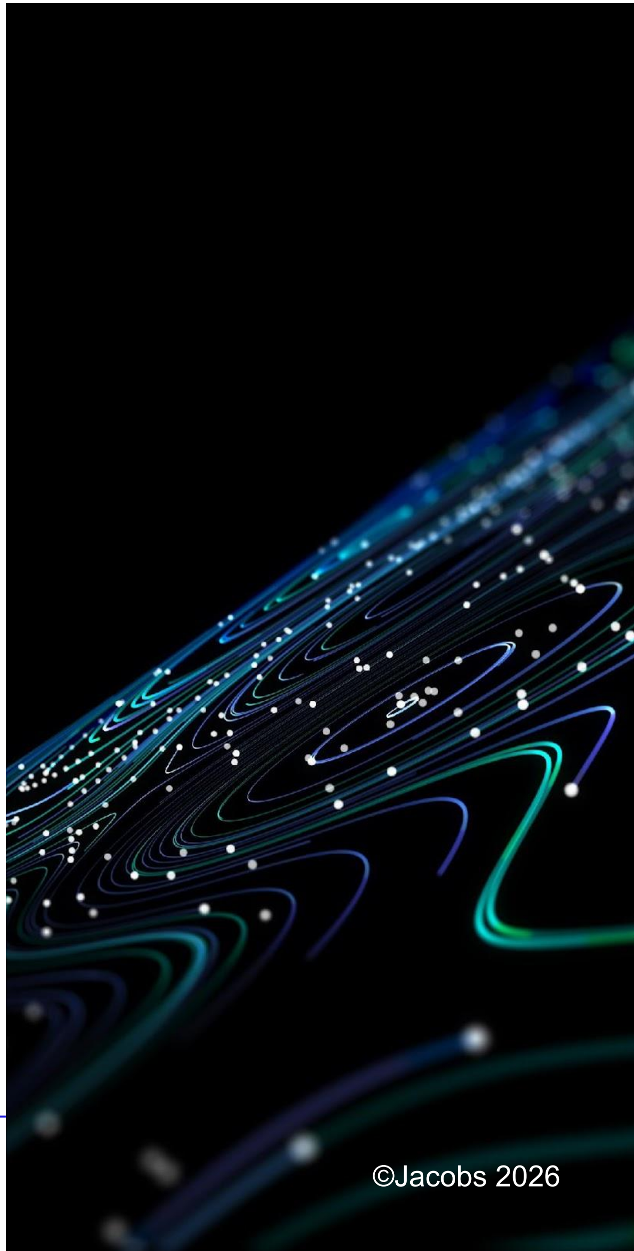
PFAS Forensic Study

- Non-target PFAS data may be needed in limited cases for advanced matching environmental data to PFAS chemical fingerprinting libraries.
- Understanding of non-target method selection, data quality objective, and regulatory acceptance is essential



Key Takeaways

- **PFAS chemistry** is complex, covers broad spectrum, and PFAS are widespread
- **Brownfield sites** are subject to both on-site vs off-site PFAS, legacy vs current operation influences increasing uncertainty in liability, redevelopment feasibility and cleanup strategy
- **PFAS impact risk mapping** determines if a background study is warranted and support decisions on RI, forensics and cleanup scope
- **PFAS forensic study** is best applied where multiple potential sources, offsite influences or unknown precursors complicate interpretations
- **Automated PFAS data processing** offers faster and more consistent interpretation of large PFAS datasets, reduce uncertainties, improve data communications, reduce cost and schedule impact
- PFAS forensics should be **applied strategically, not universally**



THANK YOU

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Overview of PFAS Gas Phase and Particulate Transport Pathways Relevant to Environmental Releases and Remediation Sites

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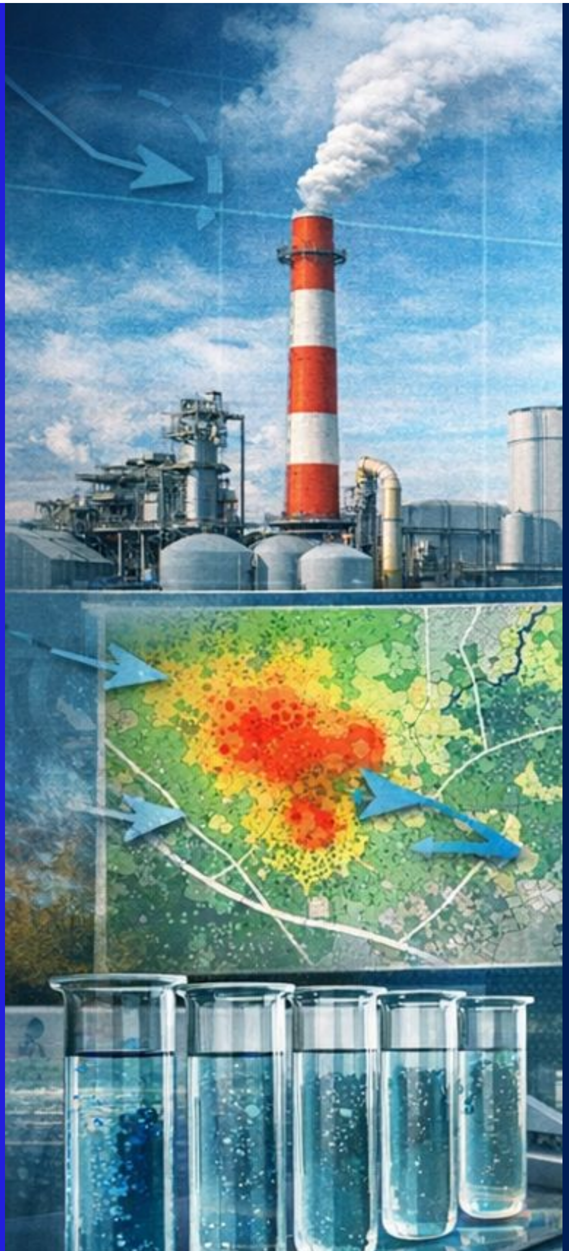

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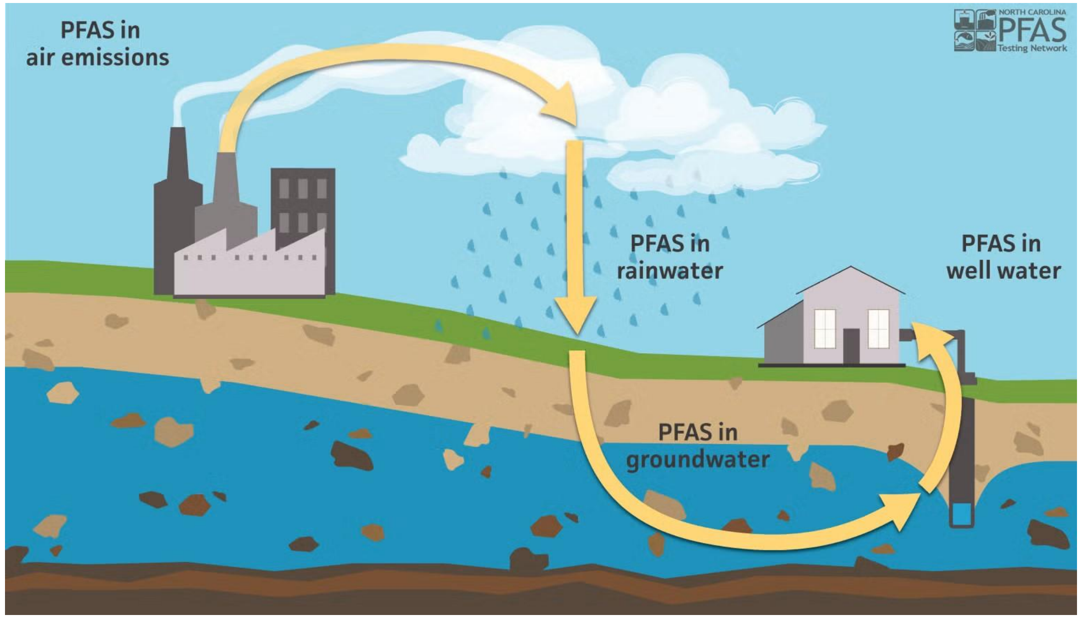
Major Classes of Air Emissions and Potential Routes of Exposure

- Air emissions from point sources (stacks, pipes) or area sources (widespread) which can then be transported through the atmosphere regionally or globally
- Emissions from consumer products directly into the indoor environment
- In general, coarse particulate settles closer to the emission source and fine particles are transported farther.



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States' Activities – Air

- Eight states, limited regulated compound list , reflective of each state's regulatory framework
- Most criteria based on surrogate toxicity values since air inhalation toxicity values have not been developed.
- Example: Minnesota requires air toxics emission reporting for 280 individual PFAS compound for facilities in 7 counties. However stack testing is not required – materials balance is allowed. https://www.pca.state.mn.us/business-with-us/air-toxics-emissions-reporting-guidance. https://www.pca.state.mn.us/sites/default/files/aq-rule2-02s.pdf
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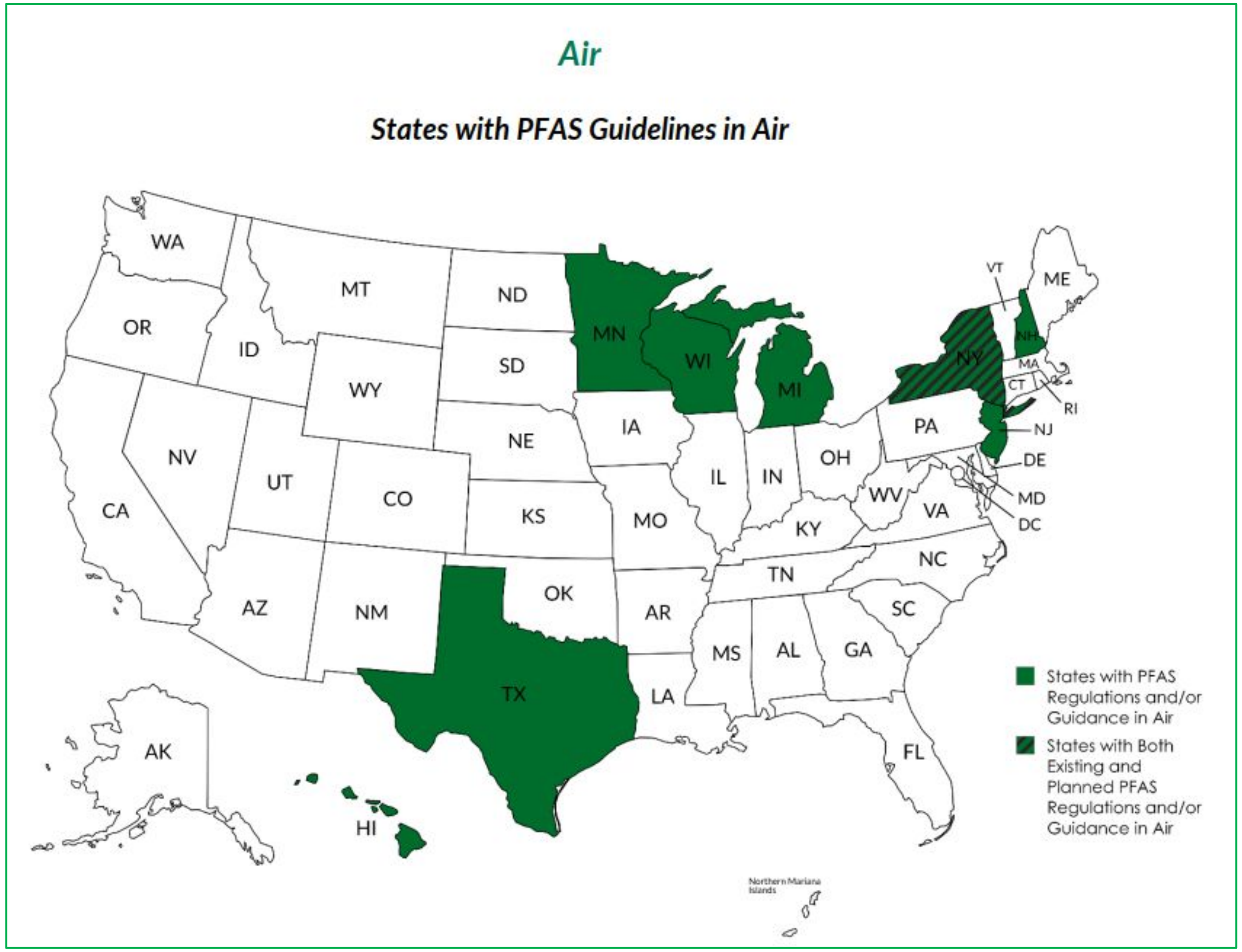
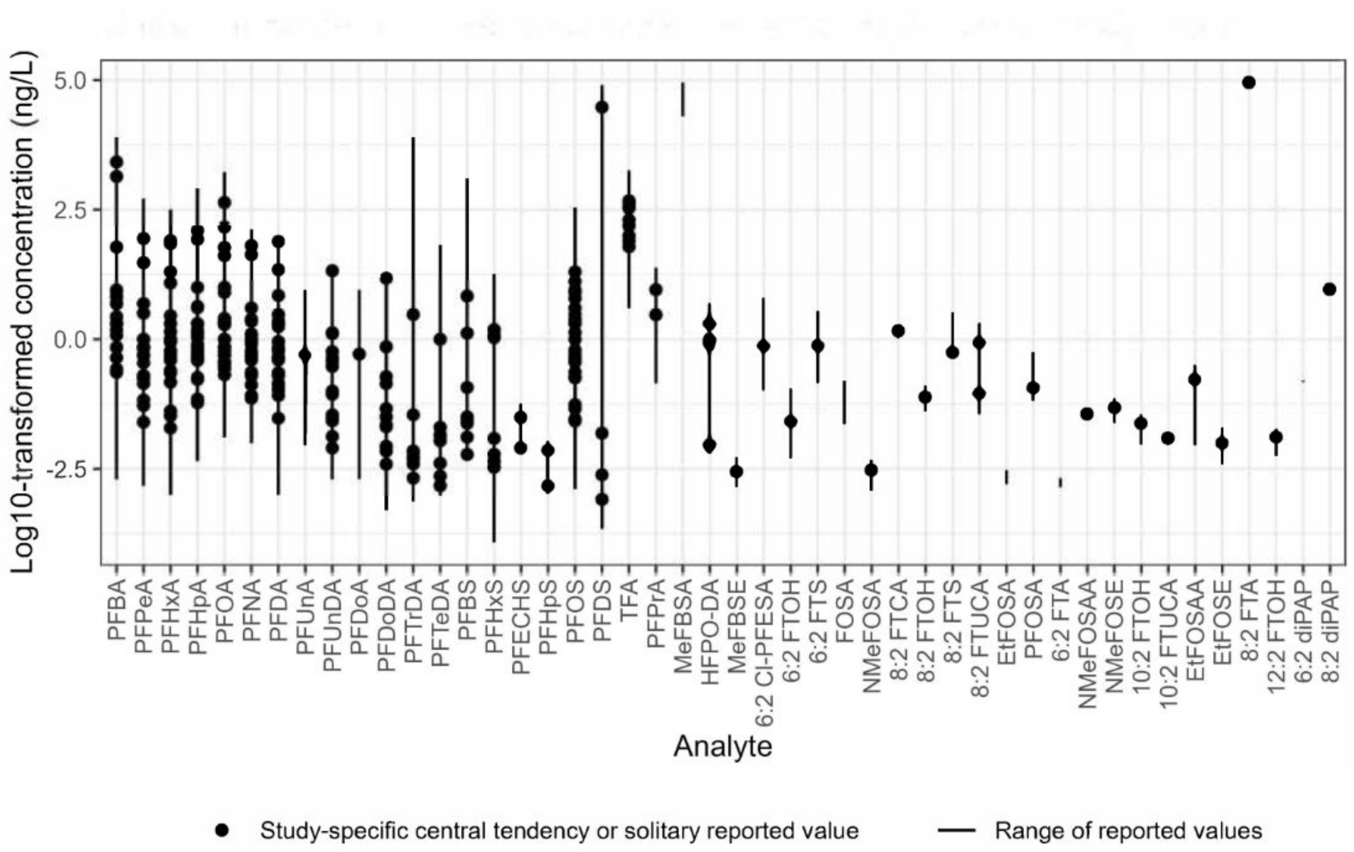


Source
ECOS Compendium of State PFAS Actions
April 2025

PFAS in Precipitation (ITRC 2026)



Sources: Barton et al. (2017), Casal et al. (2017), Casas et al. (2021), Chen et al. (2019), Garnett et al. (2021), Gewurtz et al. (2019), Kim and Kannan (2007), Lu et al. (2018), MacInnis et al. (2019), Pike et al. (2020), Taniyasu et al. (2008), Wang et al. (2019), Xie et al. (2020), Yeung et al. (2017), Zhen et al. (2015)

Figure 6-1D. Observed PFAS concentrations in precipitation.

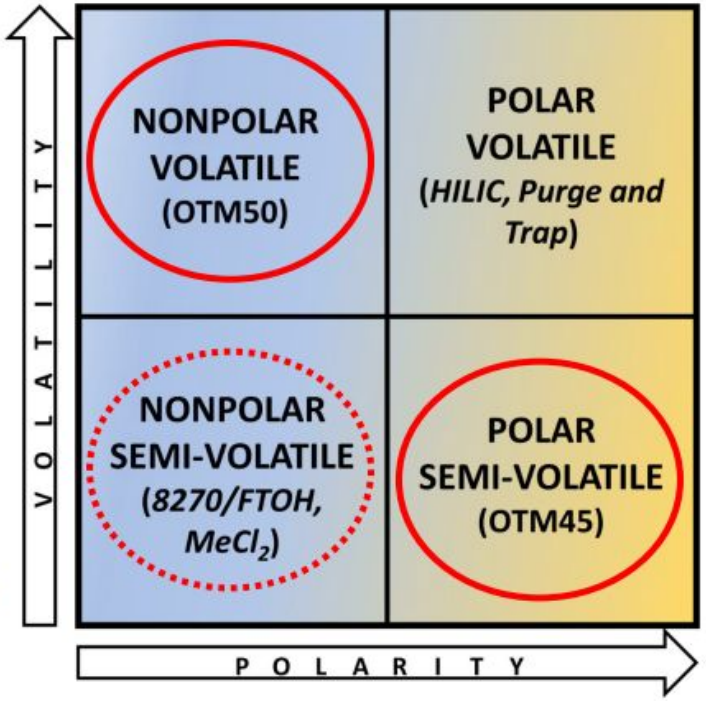
Because PFAS Have Such Diverse Structures, Many Different Methods are Required

United States Environmental Protection Agency

PFAS Sampling and Analysis

- **Canister sampling (OTM-50) with GC-MS analysis**
- 30 targeted volatile fluorocarbons
- Primarily known PICs (products of incomplete combustion), some industrial PFAS

- **Method 0010 sampling with 8270 GC-MS analysis (future OTM-55)**
- Targeted analysis for fluorotelomer alcohols (FTOHs), select 8270 compounds and potential PICs
- Includes potential compounds of concern



- **Not a current focus**
- Impinger sampling?
- LC analysis?
- Limited number of PFAS in this class

- **OTM-45 sampling with LC-MS/MS analysis**
- Currently includes 49 targeted analysis (and standards) largely related to drinking water methods 533 & 537.1, 1633
- PFAS (C4 and larger)

Slide reprinted from: Jackson, Stephen "EPA Tools & Resources Webinar: EPA's PFAS Air Emissions Measurement Methods", October 16, 2024

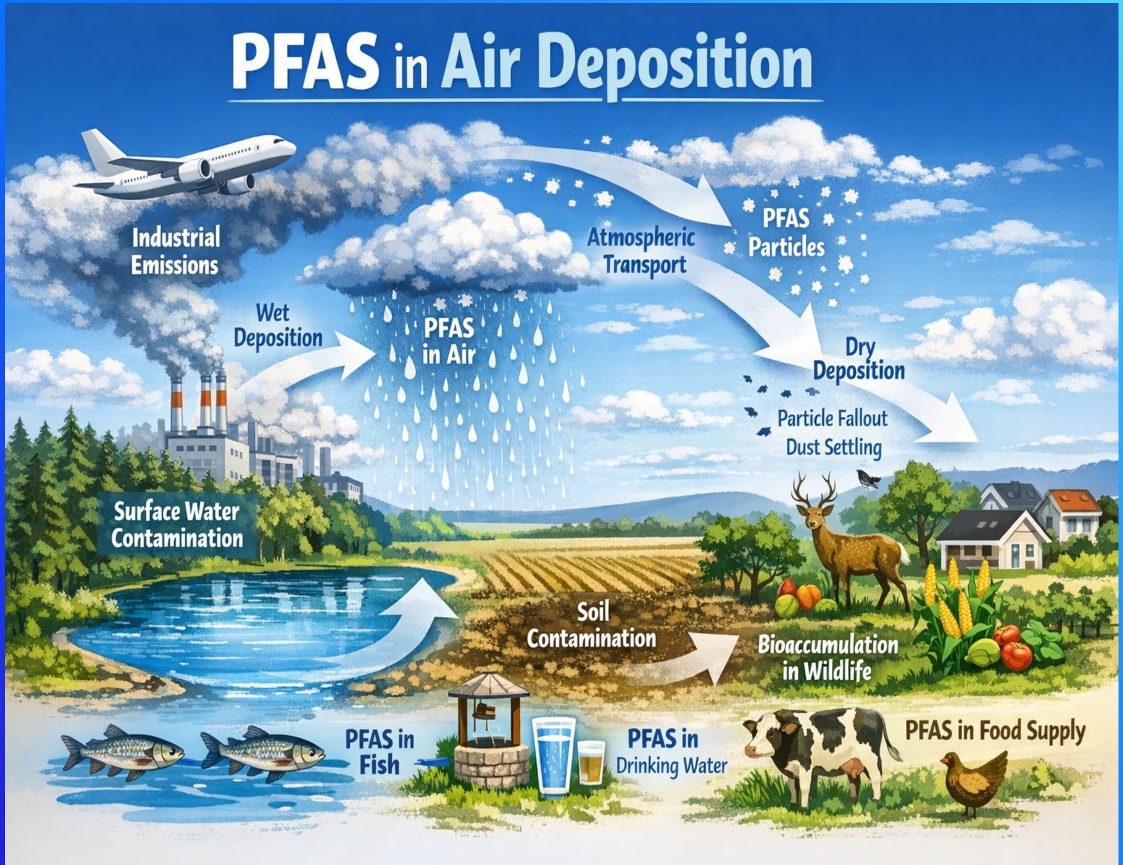
Sources that Can Contribute PFAS to Atmosphere

- PFAS production and formulation
- PFAS application as coatings, herbicides/pesticides and in metal plating
- Application of aqueous fire fighting foam (AFFF)
- Unintentional sources (more studies and data are needed)
  - Wastewater treatment plants
  - Incinerators and thermal desorption units: see EPA's Guidance on the Destruction and Disposal of PFAS
  - Municipal and industrial landfills - landfill gas wells established as a PFAS air emissions source
  - Air Strippers used in remediation

Summary

- PFAS air emissions are expected from numerous unit processes
- There are multiple routes of PFAS migration from air deposition to soils to receptors on a local and regional scale both vapor and particulate phase. These include direct inhalation and atmospheric deposition.
- PFAS regulation in air media is lacking but rapidly evolving and coming into force.
- PFAS characterization in air using current approved methods is very costly
- Strategies are required including definition of good combustion conditions, monitoring principal organic hazardous constituent destruction and/or continuous emission monitors to optimize monitoring costs.

THANK YOU



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- Hayes, H., **Lutes, C**, Natson, N., Benton, D., Hanigan, D.J., McCoy S., Holton C., Bronstein K.E., Schumacher, B., Zimmerman, J., Williams A. (2025) Laboratory development and validation of vapor phase PFAS methods for soil gas, sewer gas, and indoor air, https://doi.org/10.1039/D4EA00084F
- Brian A. Schumacher, John H. Zimmerman, Alan C. Williams, **Christopher C. Lutes**, Chase W. Holton, Elsy Escobar, Heidi Hayes, Rohit Warrier. (2024). Distribution of select per- and polyfluoroalkyl substances at a chemical manufacturing plant, Journal of Hazardous Materials, Volume 464, 2024, 133025, ISSN 0304-3894, https://doi.org/10.1016/j.jhazmat.2023.133025.
- Katherine Bronstein, Rohit Warrier and **Christopher C. Lutes**. (2023). Subsurface Per- and Polyfluoroalkyl Substances (PFAS) Distribution at Two Contaminated Sites. EPA 600/R-23/294.

Passive Flux Meters as a High-Resolution Contaminant Distribution and Site Characterization Tool

14th Annual Georgia Brownfields Association Seminar

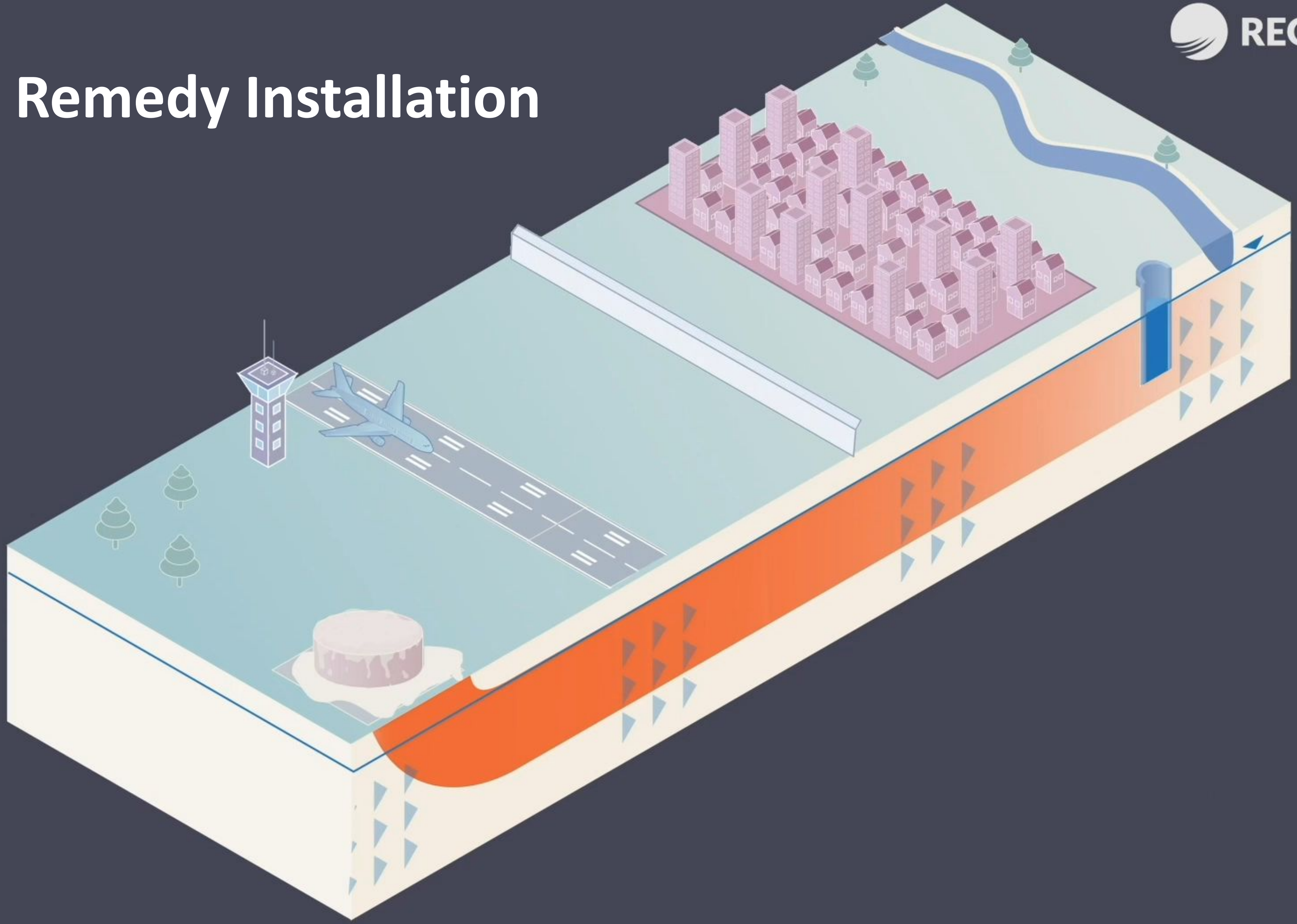
Christian Parke
Southeast District Manager
REGENESIS

Roadmap

Discuss

- Design Verification Overview
- What is Mass flux and why is it Important
- Flux tracer technology introduction
- Field Data Validation

In-Situ Remedy Installation



In-Situ Remediation Success

- **Technology selection.**
- **Adequate treatment duration for contaminant mass and groundwater velocity observed.**
    - Technology dependent. ISCO vs Activated Carbon.
- **<u>Interception of contaminant mass – both horizontally and vertically.</u>**
- **<u>Correct dose of reagent.</u>**

Design Verification

- **What is DVT?**
  - A process of data collection and analysis to verify design assumptions of a sites chemical and geological conditions and the viability of in situ injection
  - Localized, high-density identification of COC transport zones
  - Flux Zone verification
- **Why is it necessary?**
  - Site investigations typically focus on liability and risk. This is focused on confirming treatment intervals and site conditions in treatment models.
- **Focus on efficient reagent-contaminant contact**
  - Ensure accurate, efficient placement of reagents for maximum flux- interception
  - Field verification of remedial design parameters
  - Identification of contaminant transport strata

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Pre-Application Design Verification

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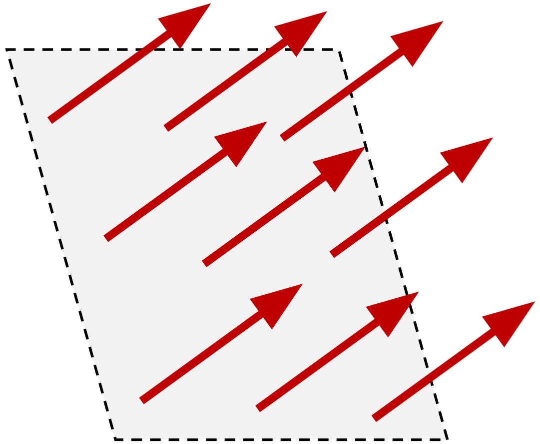
What is Mass Flux?

Flux ≈ Flow

Quantity of (contaminant, groundwater, etc.) moving through a cross sectional area versus time.

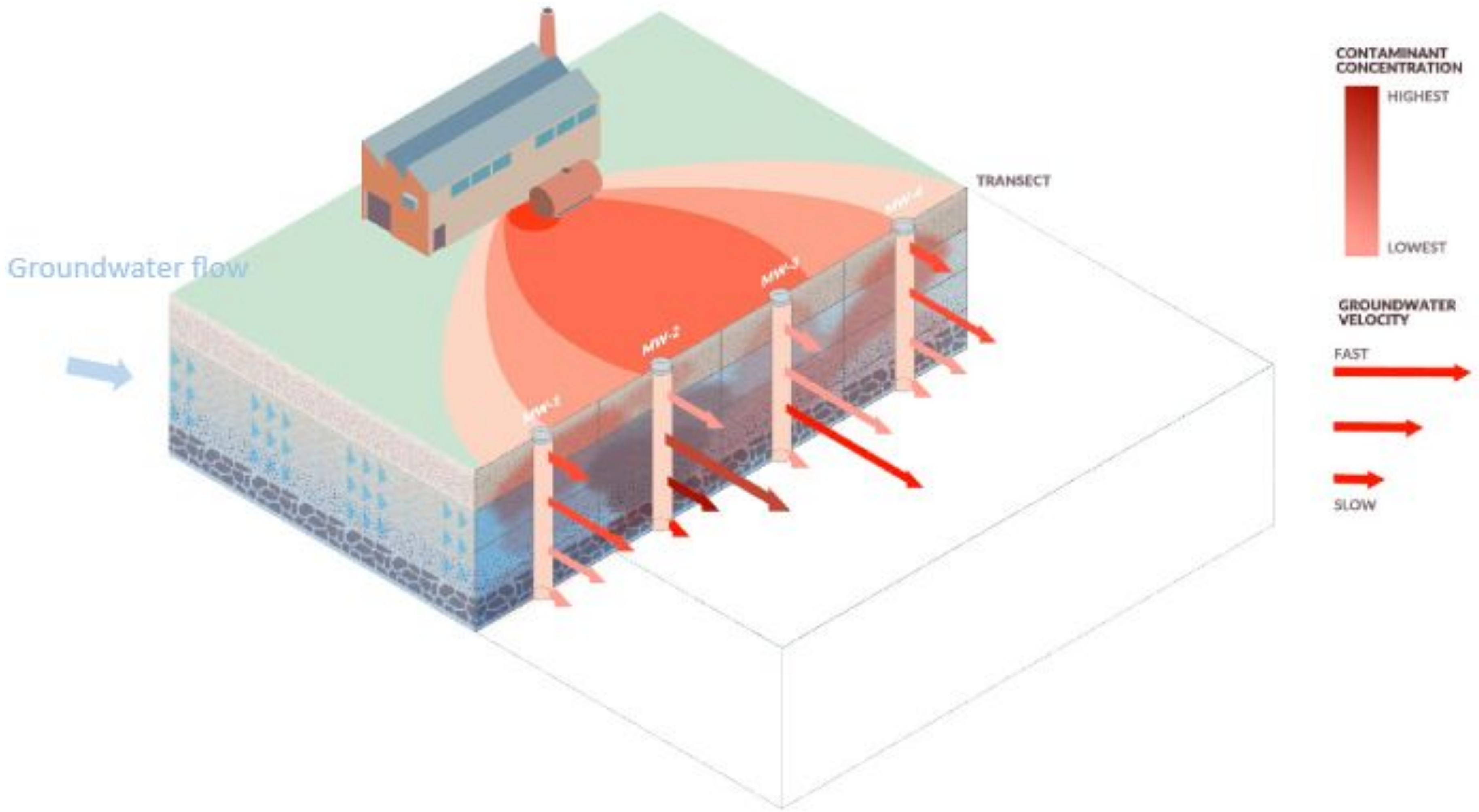


Amount of (…) passing through unit area with time

Can be:

- Groundwater (Darcy Flux)
- Contaminant molecules (Contaminant Mass Flux)

What is Mass Flux?



Graphic adapted from ITRC "Use and Measurement of Mass Flux and Mass Discharge" August 2010

Flux is rate of flow through a plane of compliance

Units

Darcy flux

(cm/d)

Mass flux

($mg/m^2/d$)

Darcy velocity (cm/d)	Seepage* (ft/yr)	Mass flux** ($mg/m^2/d$)
2	96	100
4	192	200
6	287	300
8	383	400
10	479	500
20	958	1000

*Porosity = 0.25

**GW concentration = 5 mg/L

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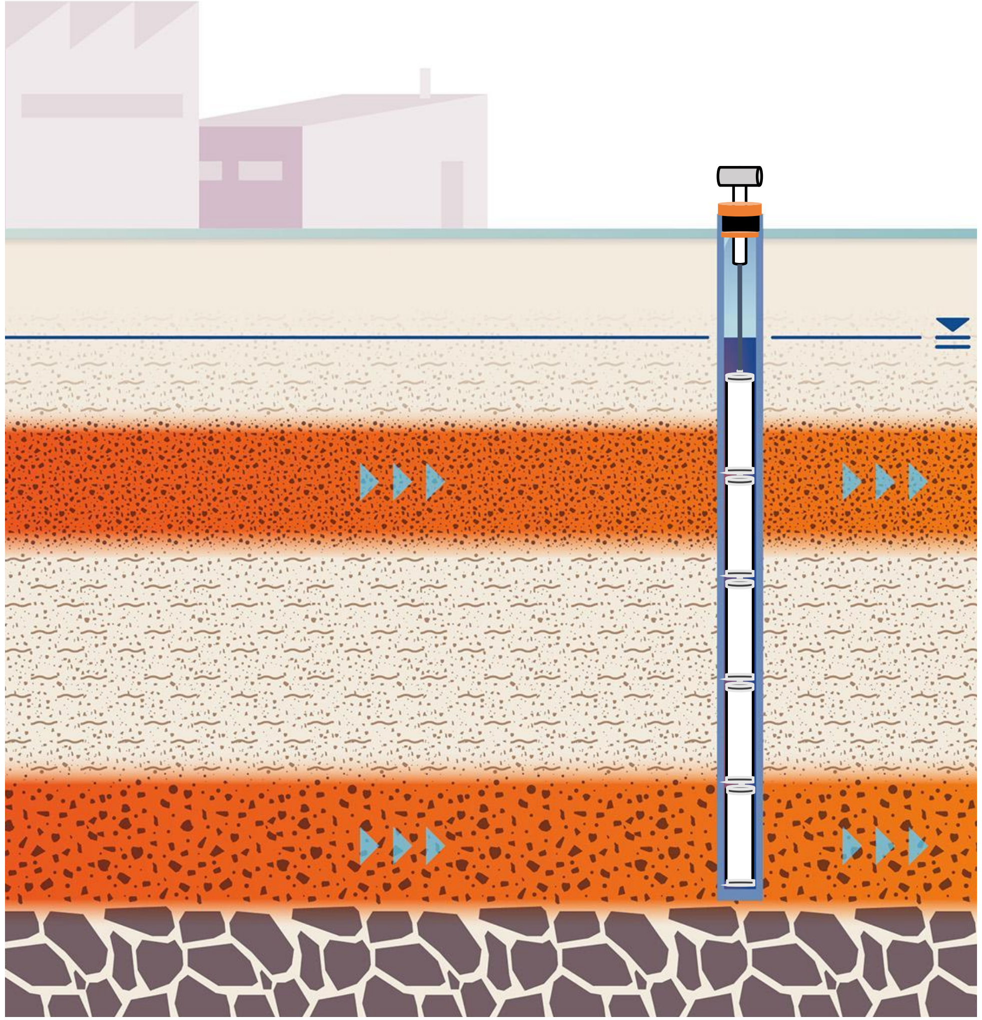
Passive Flux Determination

- Filled with sorbent media (GAC, IX) which captures contaminant(s)
- Media impregnated with leachable tracers
  - Displacement is proportional to groundwater flux
- Deployed in target well for typically 2 weeks
  - Media removed and sampled for analysis



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How Does It work?

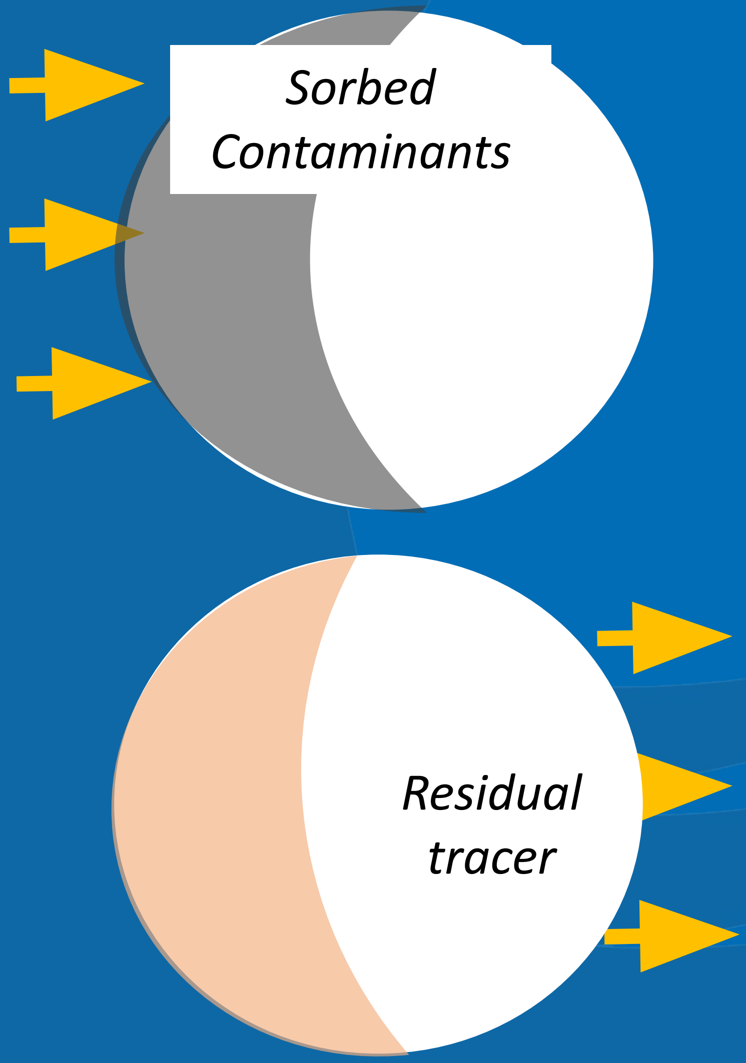
Two simultaneous mechanisms:

(1) Permeable sorbent media

- Accumulates contaminants as groundwater flows through media

(2) Soluble tracers

- Tracers are eluted as groundwater flows through media



Contaminant is sorbed to the media

Tracers desorb from media

Methanol
Ethanol
Isopropanol
Tert-butanol

Dye tracer in box aquifer

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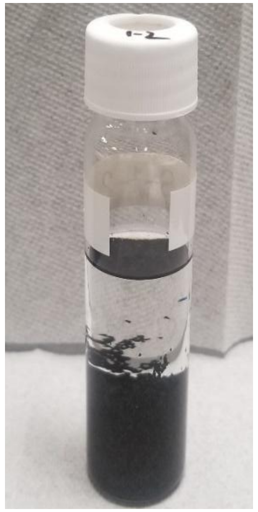
How Does It work?



Extract tracers

Extract contaminants

$$q = \frac{2r\theta R_d \xi}{t}$$

$$\xi = \left\{1 - \left[\sin\left(\frac{\pi M_R}{2} + \xi\sqrt{1-\xi^2}\right)\right]^2\right\}^{1/2}$$

$$J_c = \frac{M_c}{2\alpha r L t}$$

Darcy Velocity

Contaminant Flux

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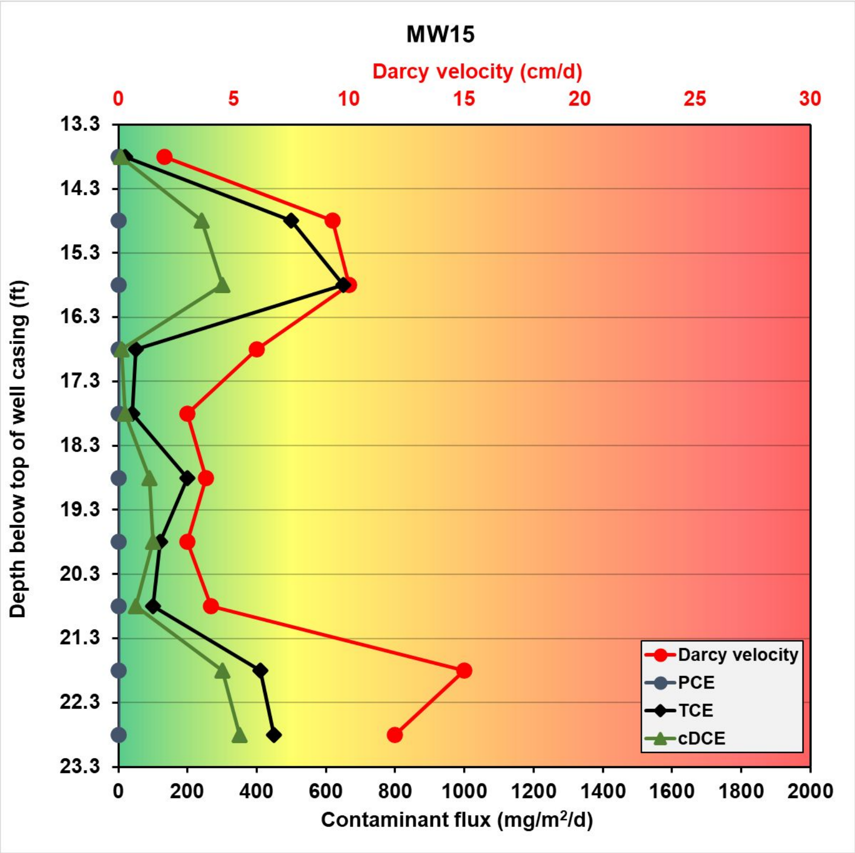
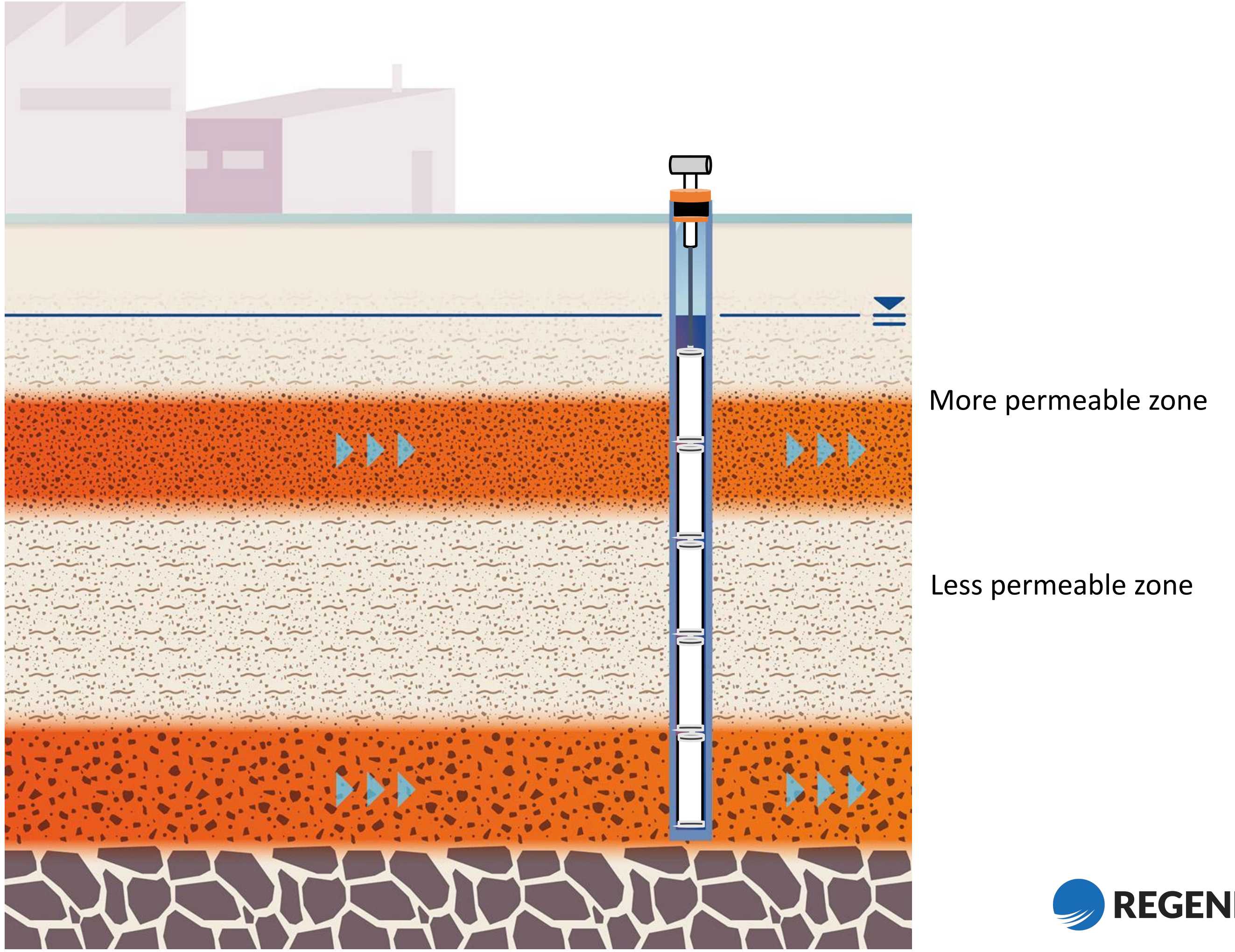
Flux Determination- Passive Methods

Resulting data identifies zones of varying flux





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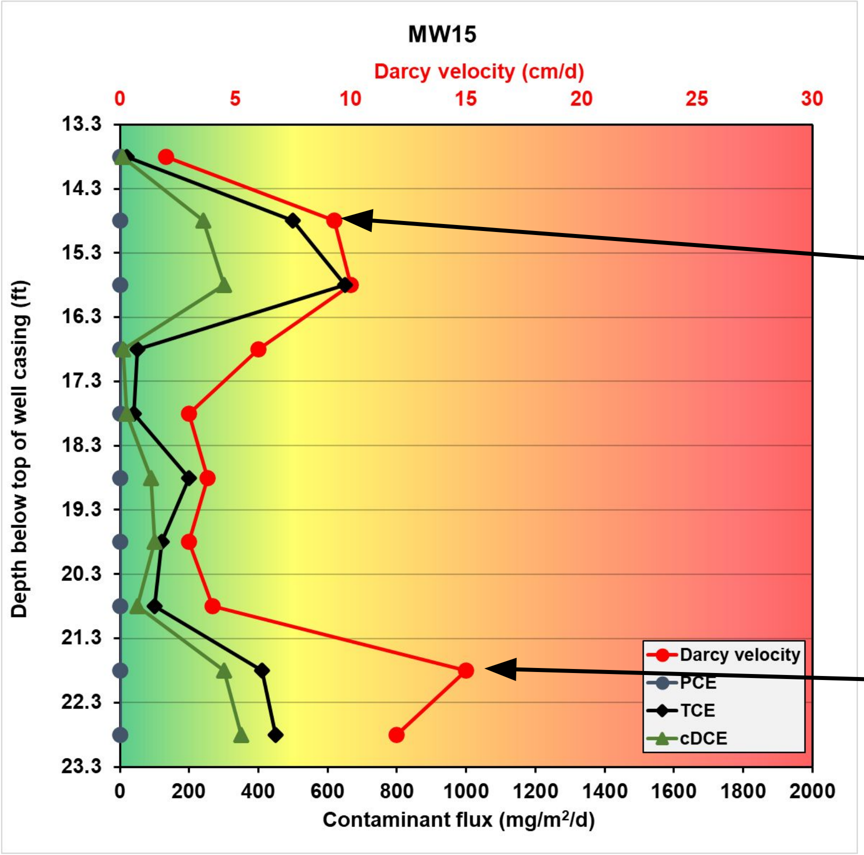
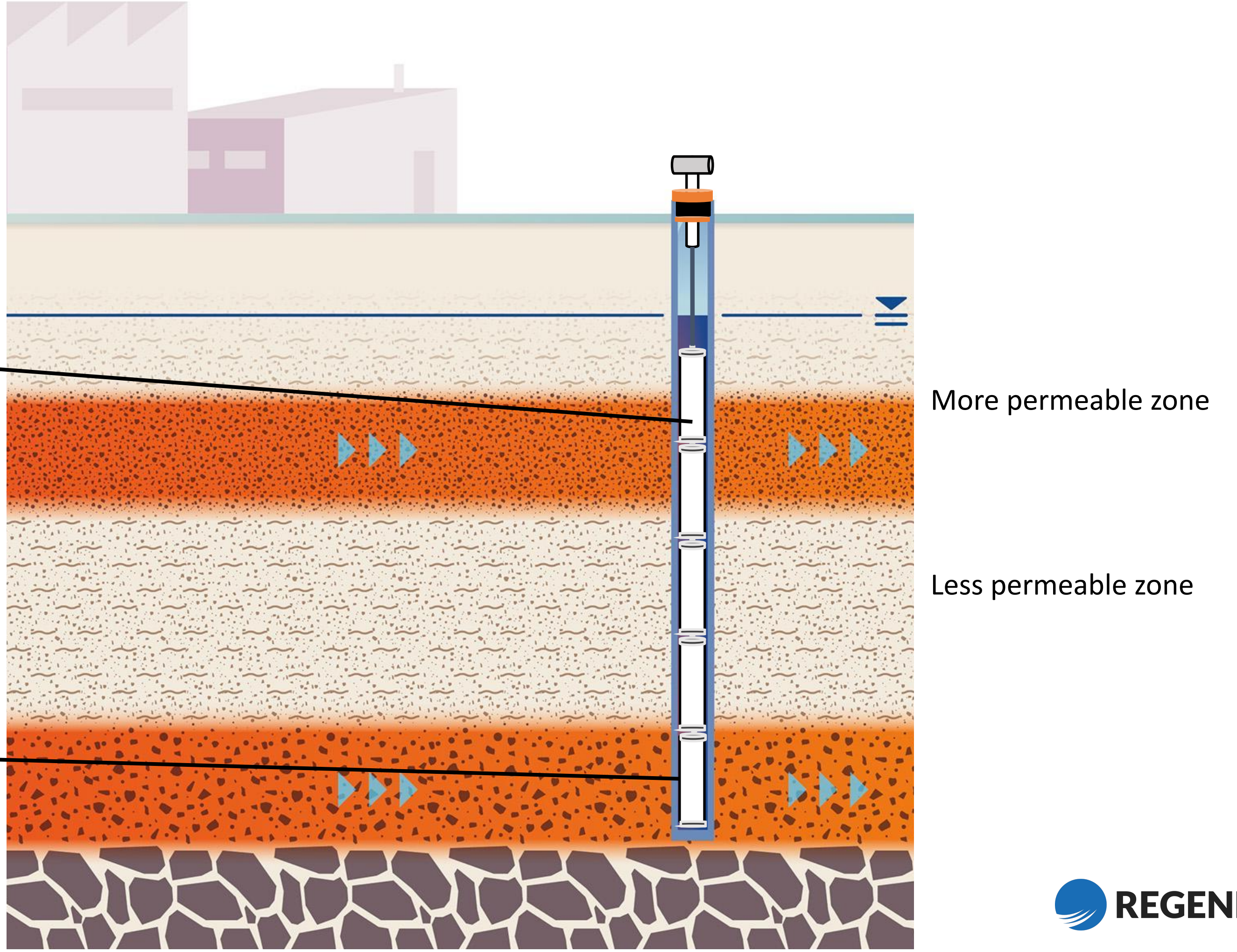
Resulting data identifies zones of varying flux





REGENESIS®

Data Reporting

Report elements

TABLE 1

Darcy velocity and contaminant fluxes

Depth below top of well casing (ft)	Darcy velocity (cm/day)	PCE (mg/m2/day)	TCE (mg/m2/day)	cDCE (mg/m2/day)
13.8	2.0	ND	20	8
14.8	9.3	ND	500	240
15.8	10.0	ND	650	300
16.8	6.0	ND	50	10
17.8	3.0	ND	40	20
18.8	3.8	ND	200	90
19.8	3.0	ND	120	100
20.8	4.0	ND	100	50
21.8	15.0	ND	410	300
22.8	12.0	ND	450	350

Site Name	ABC Factory
Location	MW15
Client	REGENESIS
Contact	John S
Well ID	MW15
Report prepared by:	Josh Moreno
Deployment length (ft)	23.25
Date deployed	10/27/21 11:30
Date recovered	11/10/21 14:30

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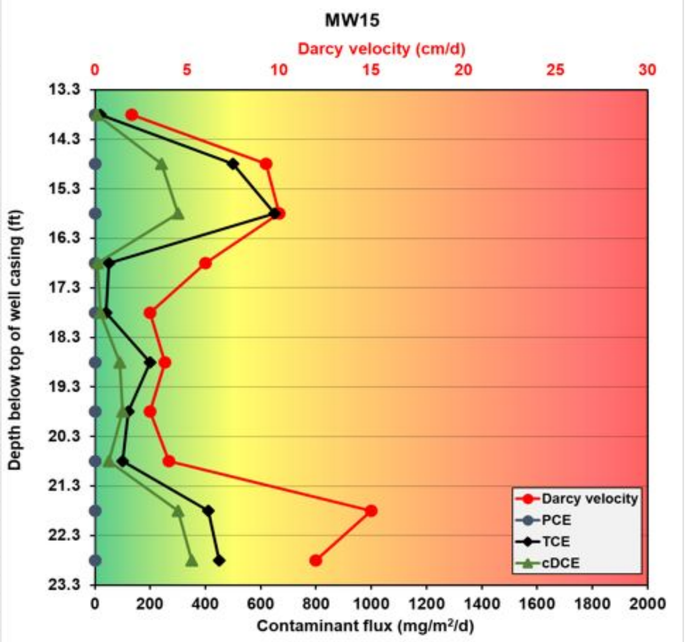
TABLE 2

Flux-derived concentrations

Depth below top of well casing (ft)	PCE (ug/L)	TCE (ug/L)	cDCE (ug/L)
13.8	N/A	1000	400
14.8	N/A	5380	2580
15.8	N/A	6500	3000
16.8	N/A	830	170
17.8	N/A	1330	670
18.8	N/A	5260	2370
19.8	N/A	4000	3330
20.8	N/A	2500	1250
21.8	N/A	2730	2000
22.8	N/A	3750	2920



REGENESIS®

Data Reporting

FluxTracer®
Flux Mapping Tool

Report elements

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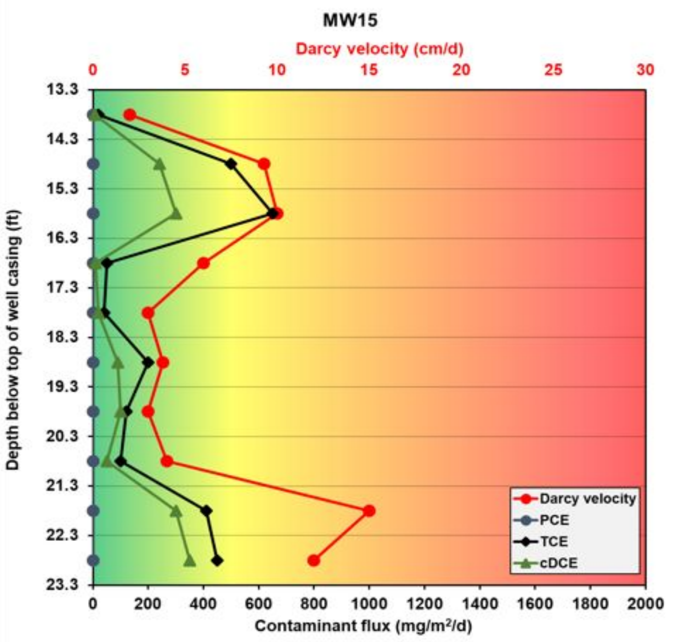

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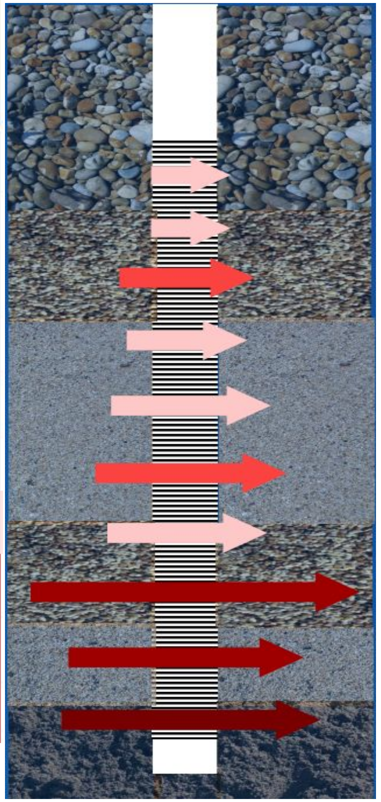
Mass Flux Varies Significantly Over Short Vertical Intervals

Depth below casing (ft)	Darcy velocity (cm/day)	PCE ($mg/m^2/day$)	TCE ($mg/m^2/day$)	cDCE ($mg/m^2/day$)
6.75	<2.0	ND	<10	20
7.75	<2.0	ND	<10	20
8.75	6.8	ND	120	190
9.75	4.3	ND	50	80
10.75	8.8	ND	70	60
11.75	9.2	ND	90	100
12.75	8.4	ND	40	50
13.75	13.1	ND	340	250
14.75	11.4	ND	240	550
15.75	12.1	ND	600	240



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Mass Flux Varies Significantly Over Short Vertical Intervals

High Mass Flux Zone

Well ID	Depth below top of well casing (ft)	Darcy Velocity (cm/day)	TCE Concentration (ug/L)	TCE flux (mg/m^2/day)	Groundwater Velocity feet/year	Soil Type (ft)
MW-1	111.8	11.6	456	53.0	556	Fine-Med Sand
	113.4	7.8	401	31.4	375	Very Fine Sand
	115.0	6.9	215	14.9	332	Fine Sand
	118.5	7.9	135	10.7	379	Fine-Med Sand
	120.1	12.2	21	2.5	583	Fine Sandy Silt
	121.7	14.9	63	9.5	716	Fine Silty Sand
		GW Velocity Apparent High>>			716	
		GW Velocity Apparent Low>>			332	
		Overall Average GW Velocity>>			490	
		Average Transport Zone GW Velocity>>			466	

2x variability in velocity is common

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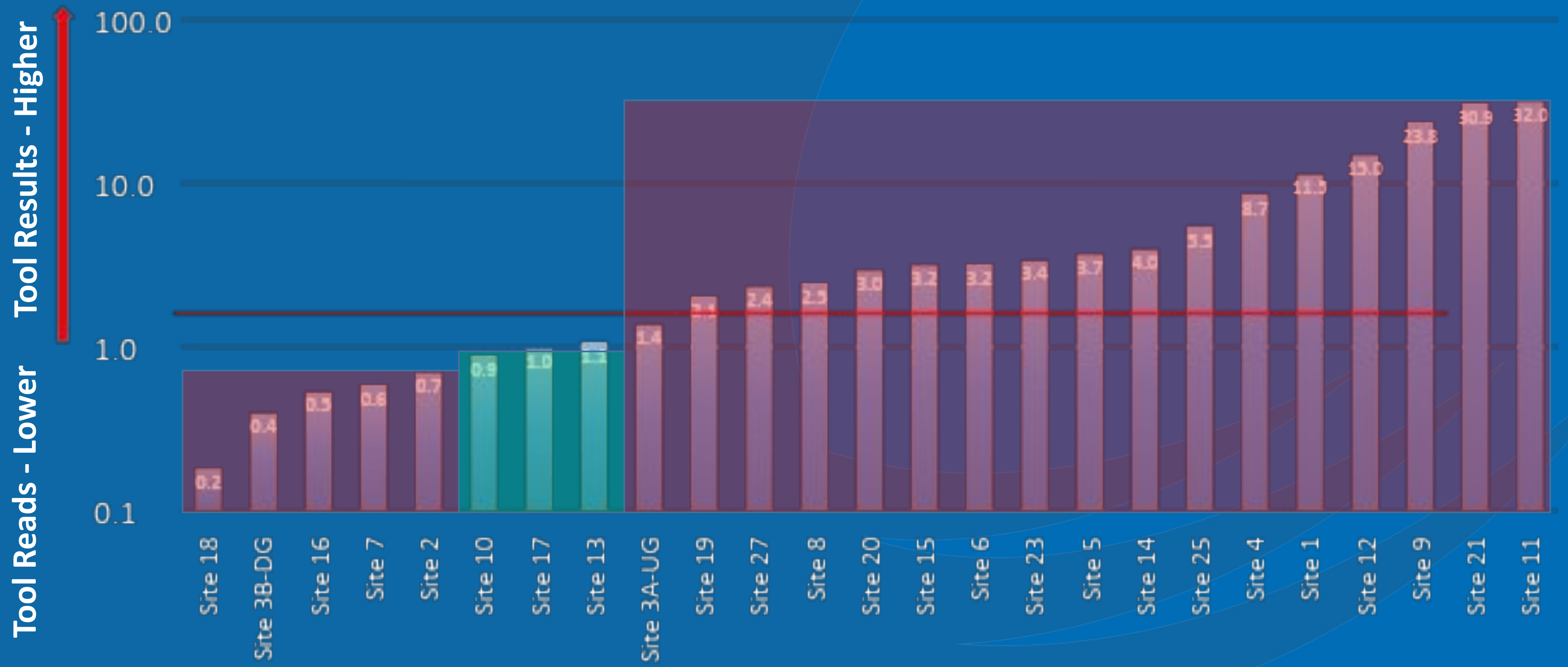
Groundwater Velocity Comparisons
Weighted Average Flux Tool vs. Bulk Aquifer Measurements



Water Supply Measurement Methods can Significantly Underestimate Velocities in Flux Zones

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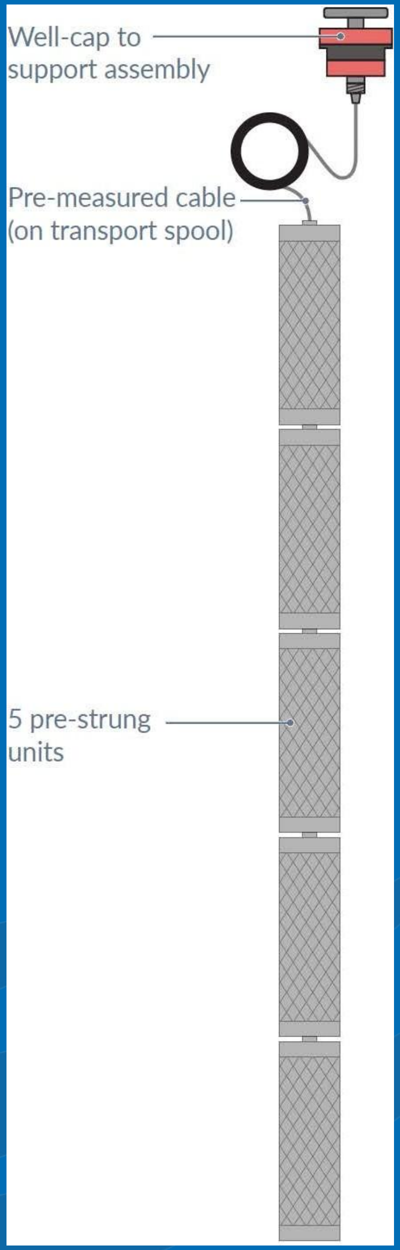
Summary

Key Benefits of DVT and Flux measurement

- Better site characterization and more specific design choices lead to better remedial outcomes
- Collects information to aid in site characterization and remedial designs
- Quantifies both flow and contaminant concentration in one step
- Vertically delineates contaminant mass flux and groundwater speed within an existing monitoring well
- Reduces potential sources of error.



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Thank You!

Christian Parke
Southeast District Manager
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cparke@regenesis.com